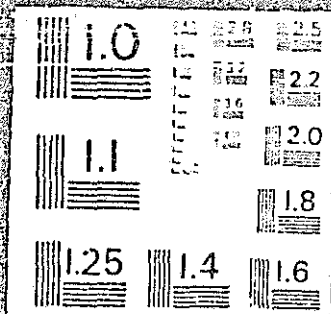


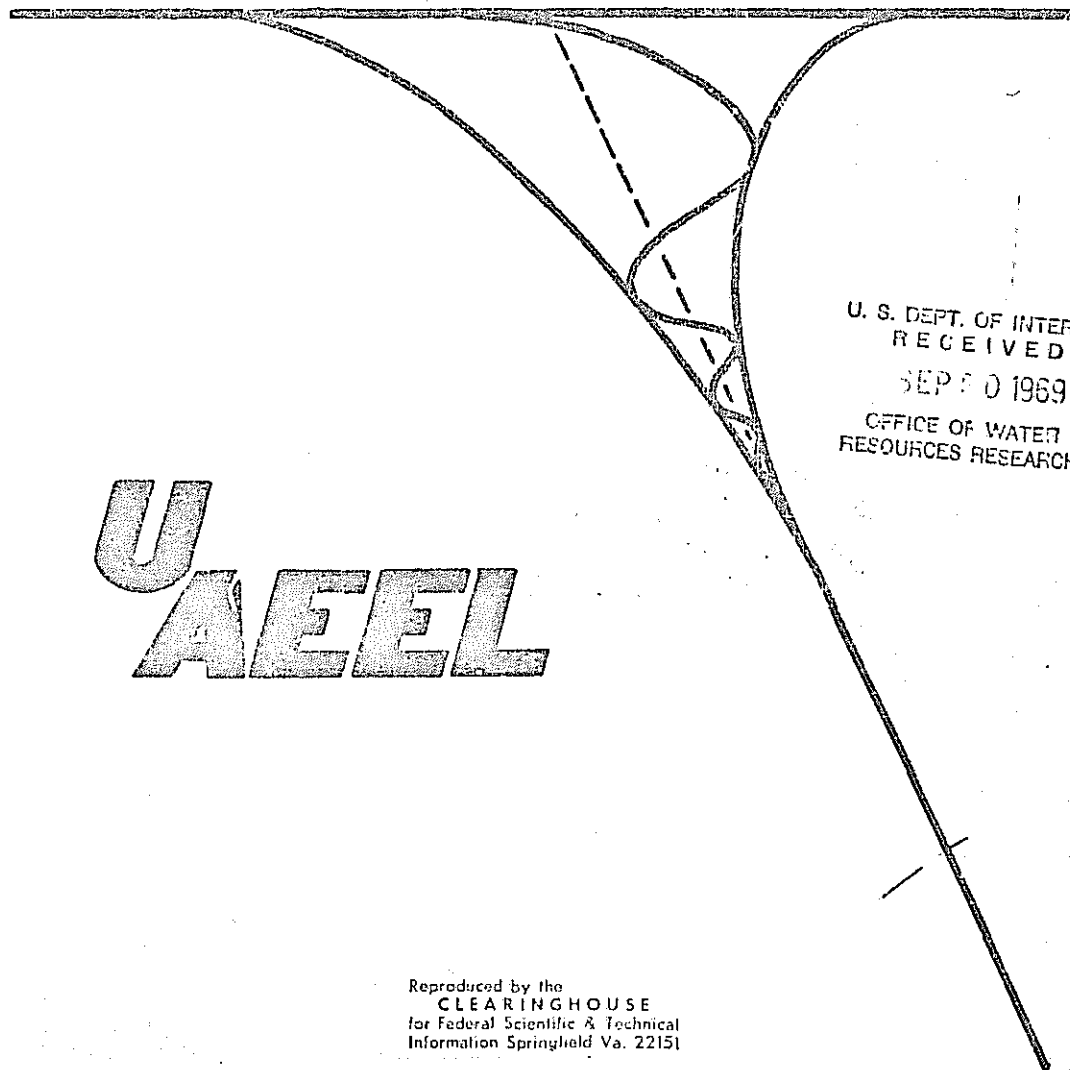
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University of Alaska  
ARCTIC ENVIRONMENTAL ENGINEERING LABORATORY  
and the  
INSTITUTE OF WATER RESOURCES

Research Report Number 4

SALINE CONVERSION AND ICE STRUCTURES  
FROM ARTIFICIALLY GROWN SEA ICE

3!

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Saline conversion and ice structures from artificially grown sea ice  
H.R. Peyton, P.R. Johnson, C.E. Behlke

SALINE CONVERSION AND ICE STRUCTURES  
FROM ARTIFICIALLY GROWN SEA ICE

H. R. Peyton, Principal Investigator  
P. R. Johnson, Associate Investigator  
C. E. Behlke, Consultant

September 1967

## Saline Conversion and Ice Structures from Artificially Grown Sea Ice

### ACKNOWLEDGEMENTS

This project was accomplished under a matching grant between the Office of Water Resources Research, Department of the Interior, and the University of Alaska, Arctic Environmental Engineering Laboratory. Funds available under this grant purposefully did not anticipate the heavy logistic expense in moving the project and equipment from Fairbanks to Kotzebue, Alaska. Therefore, a major third contributor was the Alaska Air National Guard, Kulis Air Force Base, Alaska. The support offered by the officers and men of the Alaska Air National Guard was excellent and greatly appreciated.

# Saline Conversion and Ice Structures from Artificially Grown Sea Ice

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## ABSTRACT

The environment of cold regions is generally viewed as inhospitable, primarily due to application of ideas, processes and techniques suitable to temperate zones. The work herein is a step toward solving two environmental problems. The first involves the supply of inexpensive, potable water in Arctic regions, the lack of which is a severe detriment to development. Although water does exist in the Arctic, it is neither available in potable form during many months of the year nor does it occur in sufficient quantity near the point of use. Principally, this lack is caused by the aridness of the Arctic and the shallowness of fresh water sources which, for all practical purposes, do not exist but freeze completely each winter season. The remaining liquid water source is the sea. Arctic problems are then similar to other arid regions where the conversion of sea water to potable water or the transmission of potable water to desired locations is necessary. Cold temperatures generally preclude transmission except over very short distances.

Desalination by freezing sea water is a much reported process and has been included among the desalination processes under study worldwide. The advantage of this method in the Arctic is the cold winter-time temperature for freezing and the existence of adequate solar energy in the summer for melting self purified ice. Power requirements are greatly reduced using these natural phenomena.

The second aspect of this study concerns the use of artificially grown sea ice as a structural material, thinking primarily in terms of coastal facilities such as docks, jetties, islands, platforms, etc. At sufficiently high latitudes, the summer ablation can be controlled to the point where major structures can be maintained intact during the summer. The unit cost of material is quite low because of low energy requirements.

The results of this study show that each of these sea water uses have considerable promise. Desalination to potable level was accomplished. Ice growth rates were obtained which indicate that ice structures of substantial size can be built.

## INTRODUCTION

### 1.1 Desalination of Sea Water

Availability and cost of potable water in the Arctic precludes development which could otherwise be expected in a more temperate climate. In certain areas, the problem is simply one of the technical infeasibility of transporting water from its source to the point of use due to the cold winter season and the difficulties in maintaining unfrozen pipelines. Another problem is the general lack of potable water in the vicinity of need. Some of these problems can be

fairly easily resolved by the construction of deep reservoirs to provide adequate winter storage, even though a thick ice mantle grows on the surface. Such reservoirs can be filled in the summer, used during the winter, and replenished the following summer. This method seems to be a reasonable solution for general application except for two serious complications.

The first concerns the general quality of both ground and surface waters in cold regions. The most difficult contaminants with which to deal are organic compounds with complexed iron which yield raw water substantially below acceptable domestic and industrial standards. Treatment for iron removal is one of the more difficult and expensive processes used in treatment plants today; it is doubly so when the water use is small, as will be the case for some time to come in a great part of the Arctic. The second fact concerns the separation of natural impurities in the water during the freezing process such that the upper ice mantle in a reservoir is virtually pure water with the impurities concentrated in the underlying liquid water. These additional impurities often require large volumes of dead storage to provide adequate dilution.

A need then exists for a low-cost supply of high-quality potable water at the point of use. Not only does this need for potable water exist for the present population of the Arctic, but a large need is seen in the immediate future for the extractive industries. An example is the thousand gallons per hour of high quality water needed during drilling operations for oil, and Arctic Alaska has been proved to be oil rich.

One promising approach is desalination of sea water by natural freezing processes during the winter, subsequent brine drainage in early spring, and the collection of high quality melt-water during the summer to be stored in reservoirs and used during the succeeding winter. If the melt can be made sufficiently pure, the storage requirements can be minimized well below that required for surface water.

The absolutely minimal cost of desalination is dictated by power costs. The annual replenishment of reservoirs--as noted above--requires power only for pumping. No power would be required for either melting or freezing, these being a natural product of the environment.

## 1.2 Ice Structures

Coastal facilities along polar region coast lines are very difficult to build economically because of the exceedingly large ice forces imposed against them during the winter months. In some cases the modern technology of using steel and concrete is yet inadequate to be even technically feasible. A study by the University of Alaska has shown that ice itself is a very tough and strong material; this being particularly true for sea ice. Design and construction of structures to withstand ice forces has been carefully studied through



the establishment of design criteria for offshore drilling platforms in Cook Inlet, Alaska, where the climate is much less severe than in the Arctic. These criteria were very difficult to satisfy with normal structural design concepts.

Experience in the Arctic Ocean and adjoining seas has clearly demonstrated that large masses of ice similar to Ice Islands T-3 and Arlis II withstand the forces imposed by the adjoining sea ice very well. There certainly are situations in which such large ice masses are unfavorably loaded and failures occur; however, the circumstances are those which occur naturally and could be carefully guarded against by appropriate design and operation.

Construction of very large ice masses by man should provide a useful alternate to the normal steel and concrete structures but would be feasible only if costs are competitive and performance adequate. The types of structures for which a need now exists include jetties, breakwaters, docks, piers, and platforms for certain operations such as the commercial production of oil. The latter assumes particular importance when viewed in the present perspective of the success that oil companies have experienced in extracting off-shore oil, and in view of the very large areas of continental shelf adjacent to United States cold regions. Excepting the control of summer ablation, the most crucial factor to the feasibility of such structures is cost. Here again, as in desalination, the irreducible minimum is the energy requirement, and as before the environment provides a situation in which only pumping energy is required.

### 1.3 Brine Separation

The separation from brines in sea water from ice occurs by two mechanisms.

- (1) Growth Process: As with all crystal growth, ice tends to form in a pure state and excludes impurities during crystal formation. Two of the better references on this principle are Malmgren (1) and Nelson and Thompson (2). These references explain in some detail the general exclusion of brines during the growth process and certain features of the entrapment of brines between ice crystals but within the ice matrix.

In normally grown ice sheets, there is a net reduction in salinity from the 35 o/oo (parts per thousand) for sea water to 5 o/oo for average sea ice. Such brine exclusion occurs at relatively low ice growth rates in an open system wherein the ice is formed floating on the sea and the excluded brine is diluted in the underlying water. Such conditions would not be expected in a closed system in which a volume of sea water was frozen in some manner of containment. All of the brine would be contained in the volume and the initially frozen ice would contain much less brine than that ice which was frozen last.

- (2) Brine Migration: The knowledge of brine migration from the ice after formation is ancient. Eskimos have made use of this process by obtaining potable water from well drained sea ice pressure ridges in the spring. Sufficient time and warm weather has allowed brine migration and yields a melt of high quality. A general reference to this process is Kingery and Goodnow (3).

#### 1.4 Heat Transfer

Ice sheets in cold region seas grow in thickness to about seven feet during a single growth season. This amount of growth is much less than desirable for the applications discussed and is restricted because of the insulative effect of the ice sheet itself as it increases in thickness. Acceleration of growth rate could obviously be best accomplished by reducing the thickness of ice through which the heat must transfer from the unfrozen water to the air-ice interface. A process which should produce near maximum growth rate would be that of spraying sea water in small droplets into the atmosphere, thus allowing removal of substantial amounts of heat with the droplets in flight, then allowing the droplets to freeze on the ice surface before subsequent droplets are superposed. The advantages in heat transfer by radiation, convection, conduction and evaporation are obvious. One factor of interest in such a growth process is that the freezing process is in a closed system. All of the brine in the sea water is entrapped in the ice and precludes desalination during growth as outlined in (1) above. This is not necessarily disadvantageous because the second process, gravity drainage, must have continuous brine channels throughout the ice matrix to provide efficient drainage paths.

The first published reference regarding ice growth by sprinkling techniques is Dykins (4) which describes a very brief sprinkling operation at Point Barrow, Alaska.

### OBJECTIVES

The objectives of this work were twofold: the first was to roughly ascertain the brine separation during the ice growth and subsequent gravity drainage; the second was to determine the rate of forced growth which can be reasonably expected. Kotzebue, Alaska was selected as the field site for numerous reasons including ease of logistic support, need for a potable water source, need for coastal structures, and an Arctic climate. It was proposed to construct ice mounds at Kotzebue from adjacent sea water and to observe the mechanisms both of forced growth rates and of desalination processes during the course of the experiments. It seemed advisable for this first experimental season to study both objectives concurrently in the interests of investigative effort and cost. This plan is quite reasonable because of the fortuitous factor that maximum ice growth rates are achieved with the

ice-surface temperature very near the freezing point, while the maximum gravity drainage of brine occurs with the ice mass very near its melting point. Thus, the controlling experimental parameter of both aspects are coincident because the near-freezing temperature of the surface maintains the underlying ice mass at a near-melting temperature.

## RESULTS

### 3.1 Forced Growth

Two ice mounds were constructed on the sea ice near the beach at Kotzebue, Alaska. These mounds were constructed with a variety of water dispersion devices ranging from irrigation sprinklers to open-ended pipe. No serious attempt was made to engage in a sophisticated hardware development project, but rather efforts were directed toward gaining good exploratory information concerning the topics at hand. Results, therefore, do not reflect optimum performance.

### 3.2 General Features at Kotzebue

A map of the Kotzebue vicinity is shown in Figure 1, with the study site indicated. The salinity of the sea water surrounding the Kotzebue vicinity is much lower than found in normal sea water due to the fresh water flux from rivers in the vicinity. The range of salinities measured was from 5 to 23 o/oo. The higher salinity waters were found at depths exceeding 29 feet with the fresher water near the surface. This stratification would be expected from the differential densities. The water used for the project had salinities between 5 and 7 o/oo, which was substantially less than that used by the Navy Civil Engineering Laboratory at Point Barrow (4). The lower salinity waters caused icing within pipelines and sprinkler assemblies at Kotzebue, but these problems were much less severe during the NCEL experiments.

### 3.3 Ice Growth Volumes

The main ice growth site was established and ice growing operations commenced on April 1, 1966 after several unsuccessful systems had been tried. The irrigation type sprinkler used initially is shown in Figure 2, and as modified for better performance in Figure 3. Although these sprinklers worked well in the Barrow study, their performance at Kotzebue with the fresher water was less than desirable. No real effort was made to improve them. Field fabricated sprinklers shown in Figures 4 and 5 proved more successful for this pilot study, with that shown in Figure 5 causing the least trouble. These latter devices were not optimum for ice growth, but did allow substantial ice to be grown during the period 1 April through 28 April 1966 with the maximum of 23.5 feet of ice for the period shown in Figure 6.

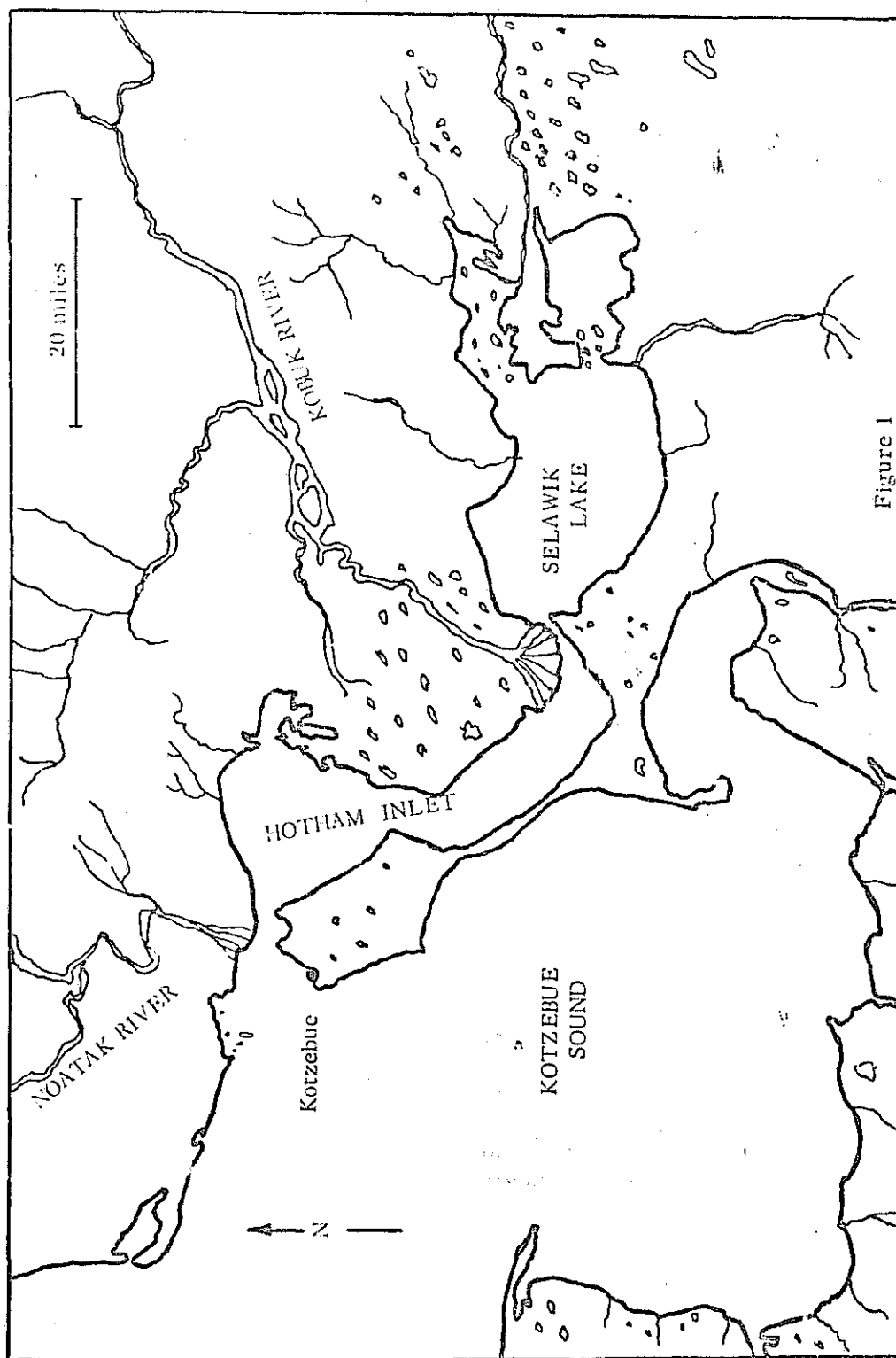


Figure 1

Figure 7 shows the contour details of the artificial ice. The mounds were built on a floating ice sheet, and those contours shown in Figure 7 are not the relief above sea level but show a somewhat greater thickness because of the subsidence of the floating ice sheet. The details of the subsidence are shown in Figure 8. The total water pumped on the site is estimated at 1,000,000 gallons, and it can be seen from Figure 7 that a substantial portion flowed away from the immediate vicinity of application. This spreading was primarily due to high salinity brines draining away leaving fresher ice behind. The details of this mechanism will be discussed in a later section. The representative profile shown in Figure 9 is indicative of the amount of lateral movement of high brine water.

### 3.4 Ice Types Grown

The relative crudeness of the application devices did not allow fine control of application rates, droplet size, or time increments between successive applications. Little difficulty was experienced when initiating growth on cold, solid ice, but considerable difficulty was experienced on snow. These problems are certainly resolvable with increased sophistication in application devices and are indicative of the care that will be necessary in the development of prototypes.

Different types of ice were formed on the mounds under various water application rates and variable ambient weather conditions. Excessive water application under cold weather conditions, below  $-20^{\circ}\text{F}$ , resulted in material with properties very similar to snow and having small ice platelets stacked in a jumbled fashion. The excess water, including most of the brines, drained through. Excessive application also caused an uneven surface as shown in Figure 10.

The volume between the two mounds was partially filled by having open pipelines spraying water into the valley between them during the later stages of the ice mound growth. High winds occurred during much of this time, and unfrozen water was forced back against one mound forming the large icicles shown in Figure 11. Figures 12 and 14 show the development of these large icicles during a week of severe weather in which winds occurred up to 35 knots and with temperatures down to  $-15^{\circ}\text{F}$ . The wind direction was along the axis of the mounds and from left to right in the figures. Effects of the very high convective heat transfer are evident on the right mound. Several observations of discrete growths attained under specific weather conditions are as follows:

1. On March 7 at  $-10^{\circ}\text{F}$ , wind about 4 knots and clear, 6 or 7 inches of ice formed in 14-1/4 hours with a freezing rate of about 0.45 inches/hour.
2. On March 25-26 with a temperature of about  $-10^{\circ}\text{F}$ , clear sky, wind

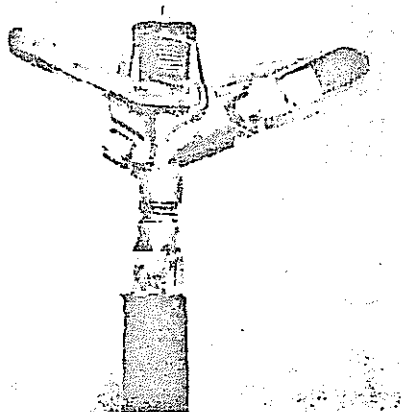


Figure 2. Irrigation type sprinkler

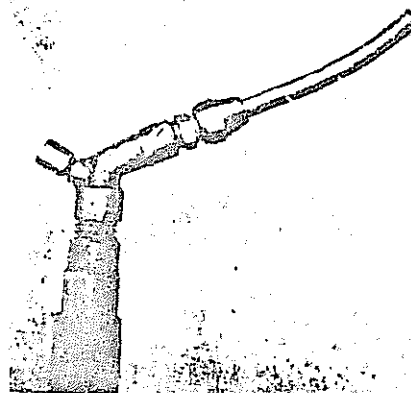


Figure 3. Modified irrigation type sprinkler

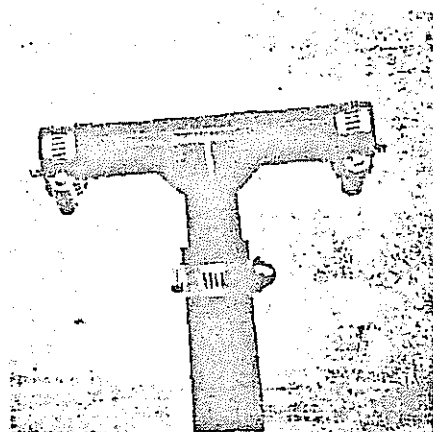


Figure 4. Field fabricated sprinkler, I

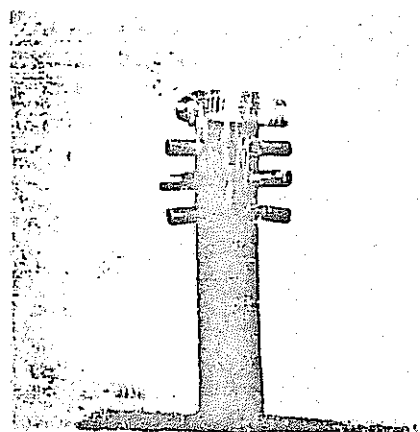


Figure 5. Field fabricated sprinkler, II

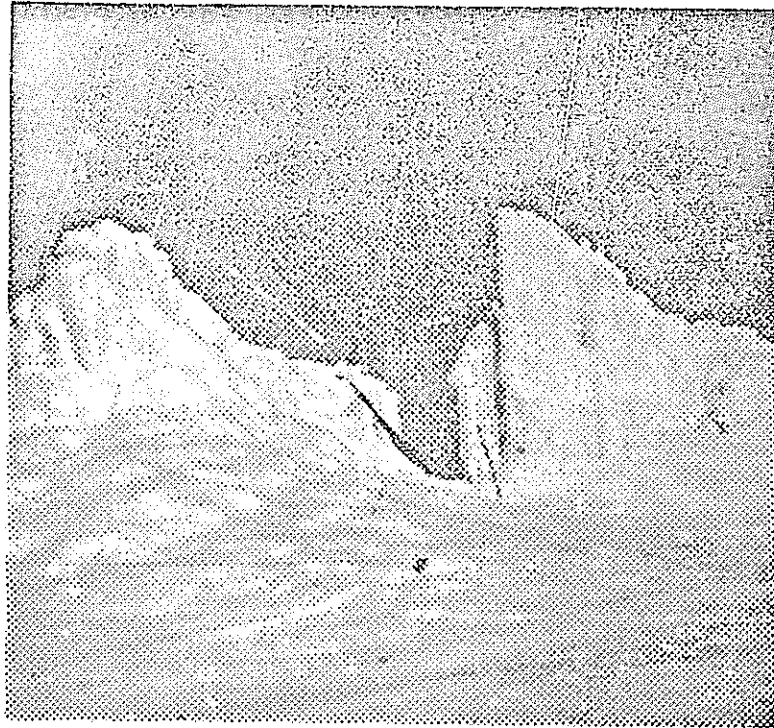


Figure 6 Ice growth during 1 April through 28 April 1966. Maximum ice growth for this period was 23.5 feet.

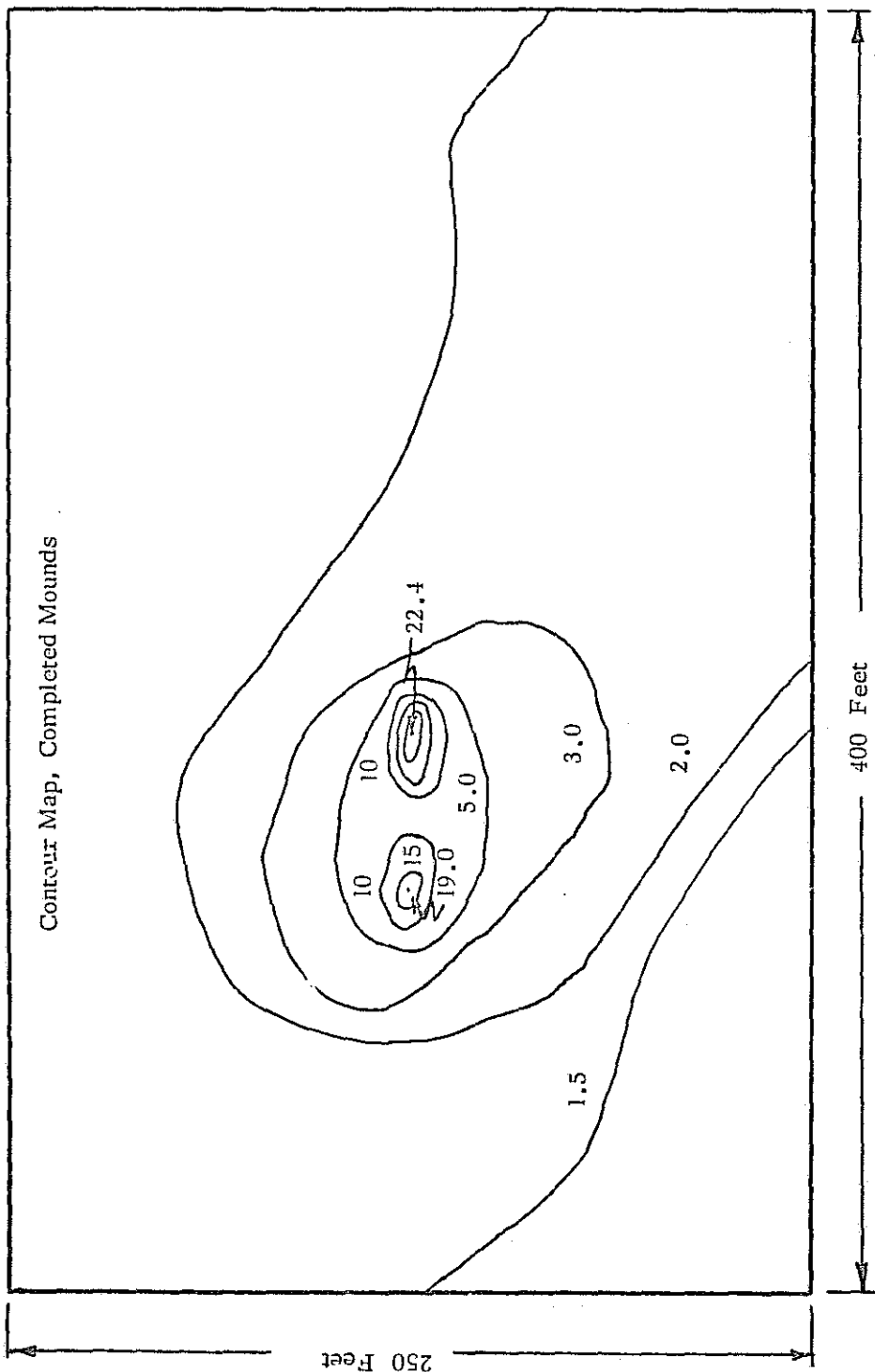
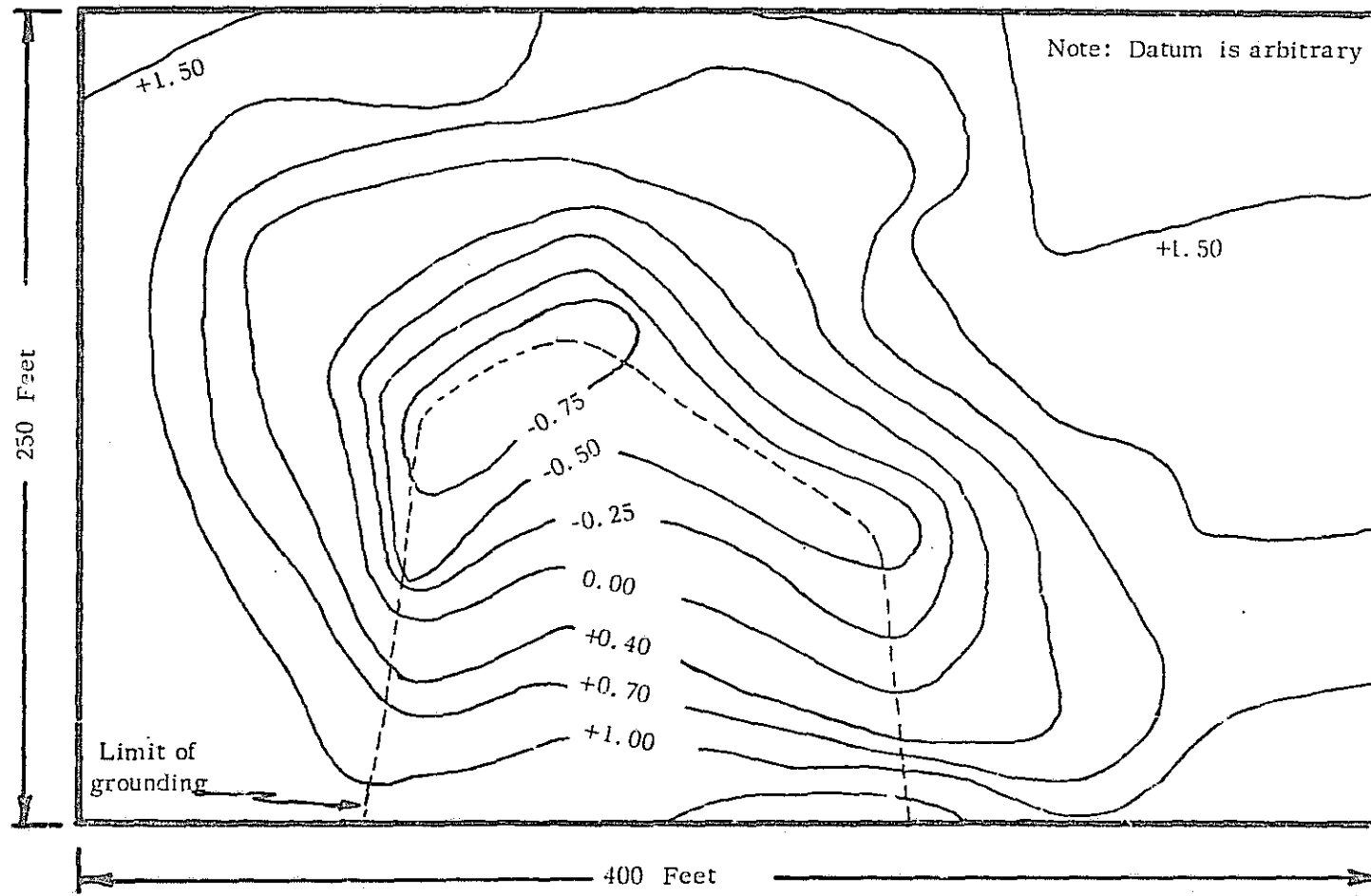


Figure 7





Contour Map, Ice Sheet Depression

Figure 8

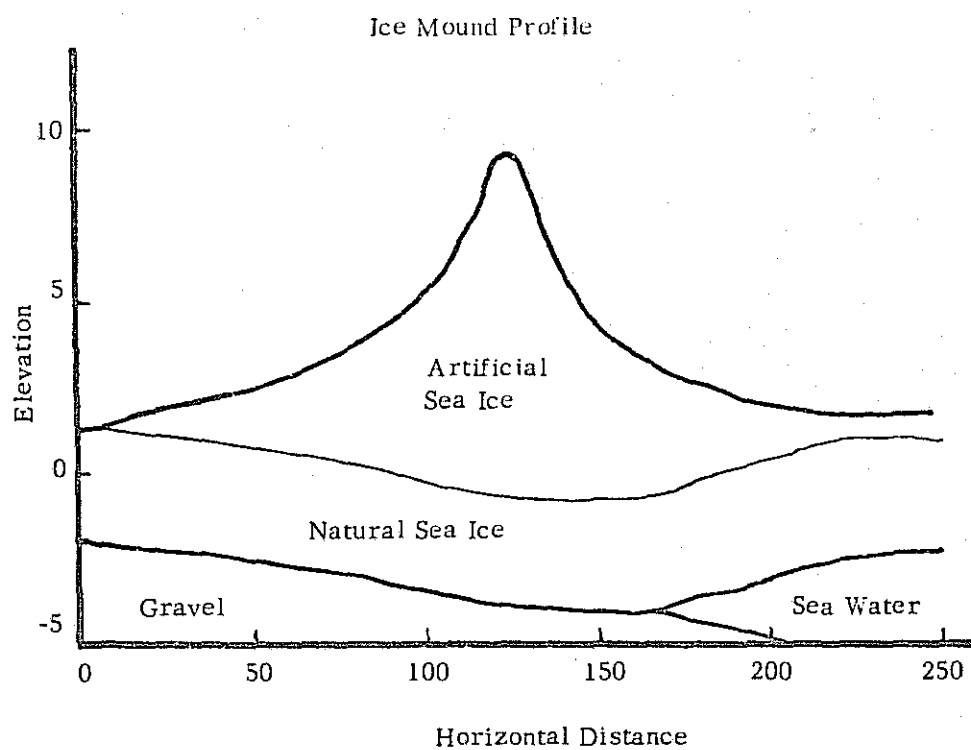


Figure 9



Figure 10      Uneven surface caused by  
excessive water application



Figure 11      Large icicle formation caused by  
high winds forcing unfrozen water  
back against the mound



Figure 12      Early growth of icicle formation



Figure 13      Mid growth of icicle formation

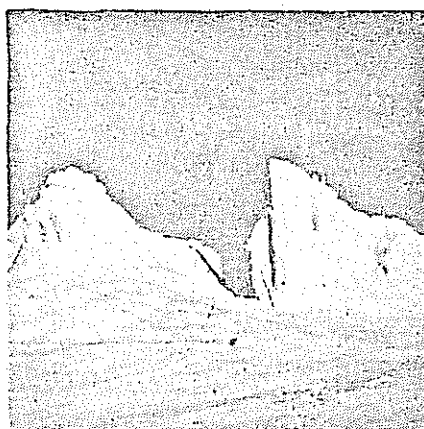


Figure 14      Final state of icicle formation

calm, 8 inches of slushy ice was made in 13 hours during the night. This ice probably contained 5 inches of solid ice which is a growth rate of 0.40 inches/hour.

3. On March 27, a shallow metal pan collected 1.9 inches of water and ice during 2 hours. Temperature  $-6^{\circ}\text{F}$ , light overcast, calm. Freezing rate was about 0.35 - 0.40 inches/hour.
4. On March 28 at  $+30^{\circ}\text{F}$ , cloudy, calm, an application rate of 0.20 inches/hour was greatly in excess of the freezing rate.
5. On March 21 at  $+5^{\circ}\text{F}$ , cloudy with light snow, wind ranging from six to fifteen knots, 6 inches of slightly slushy ice formed in 12 hours. Freezing rate of about 0.40 inches/hour.
6. On April 1-2, with temperature of  $-6^{\circ}\text{F}$ , a very light wind, high thin clouds, the freezing rate was around 0.40 inches/hour.
7. On April 4 with temperature of  $+15^{\circ}\text{F}$ , cloudy, wind 10 knots, the growth rate was about 0.25 inches/hour.

These water applications were all on impervious surfaces and are representative of growth rates which should be minimal with properly developed application equipment. Examples of applications less than optimum are:

1. On March 7 at  $-10^{\circ}\text{F}$ , wind about 4 knots, clear: a near vertical stream through a  $9/32$  inch orifice at 27 psi attained a height of about 30 feet. The accumulation was a mound of around 15 inches in height and formed in a few hours. When examined later, this ice mound had a solid ice glaze, perhaps acquired later, but was composed primarily of snow-type ice.
2. On April 12-13 with the temperature at  $+3^{\circ}\text{F}$  and the wind 6 knots, a type III sprinkler was installed on 2 feet of riser above the top of a mound which was approximately 15 feet above the level of the surrounding ice. The sprinkler had fourteen holes, each  $1/8$  inch in diameter, pointing generally downward from the sprinkler. This water pressure was about 25 psi. Within 2 hours of installation, snow-type ice had built up to the sprinkler, a growth rate of about 12 inches/hour. When this ice was knocked off the riser, it continued to rebuild at the same rate. The density of the ice was estimated at  $1/5$  the density of water.
3. The area of the two ice mounds was in the order of  $600 \text{ feet}^2$ . On April 19 the temperature was  $-16^{\circ}\text{F}$ , wind about 12 knots and clear. The application rate was about 1,000 gallons/hour or 2 inches/hour. It is surmised that the total water which could have been used was three times that being applied. At this time the mounds extended about 20

feet above the surrounding floe and a considerable surface area was available for convective heat transfer.

4. On April 15th at  $-7^{\circ}\text{F}$ , partly cloudy with a 4 knot wind, the application rate on one mound was 15 gpm. The water fell on a pervious surface and flowed internally out the bottom of the mound flooding adjoining ice. The growth rate on the mounds was very small.

These data show that eight to twelve inches of ice growth per day is attainable during average conditions for Arctic coastal regions. These rates could be improved with the development of more appropriate hardware; some problems requiring solution are indicated in the second list of observations.

### 3.5 Heat Transfer Considerations

The heat transfer involved in freezing sea water by sprinkling is so complicated that no attempt of analysis will be made based on these field data. Such refinement must be done under a more carefully controlled field experiment by collecting large amounts of data, including such variables as air velocity profiles, radiation flux, droplet size and velocity, air temperature profiles, specific humidity profiles, detailed water application data, and detailed ice formation data. The exploratory nature of this project precluded such data gathering, and it was inappropriate to engage in such a costly study until the general features were observed under field conditions. As with most complex phenomena, it is anticipated that the details of heat transfer in this situation will need to be studied in the laboratory at some future date because of the high variability and lack of control under field conditions.

The effect of wind on cooling of evaporative surfaces is known to be very large, and the most sophisticated approach has probably been taken by those interested in ablation cooling of nose cones for vehicles re-entering the atmosphere from space. Factors such as supersonic flow and chemical change of the surface material makes this approach questionable for this project.

Physiologists are interested in the cooling of the evaporative surface of the skin and have developed an empirical equation for use in the evaluation of freezing of flesh under windy conditions and cold temperatures.

$$K = (\sqrt{100 W} + 10.45 - W)(33 - T)$$

where K is total cooling in  $\text{kg cal/m}^2 \text{hr}$ ,

W is wind velocity in m/sec,

T is air temperature in  $^{\circ}\text{C}$ .

The term  $33 - T$  for the cooling effect on humans was modified to  $0 - T$  or simply  $-T$ , for the effect on water surfaces such as those used in this experiment. These values are shown for representative Kotzebue weather in

Table I and representative individual days during the life of the project as shown on Table II. It can be seen that the wind effect is certainly large. The physiologists' method of determining the wind chill factor partially takes into consideration the heat loss by radiation, conduction, convection and evaporation; therefore, it is a rough approximation of the entire heat transfer process with the exception that the volume to surface ratio available for evaporation and radiation.

### DESALINATION

Standards for quality of potable water are published by the Public Health Service, U.S. Department of Health, Education and Welfare (5) and their standards are listed below.

1. The threshold concentration at which NaCl in water is detected is around 300-350 mg/l. (0.30 - 0.35 o/oo).
2. The threshold concentration for detection of sea water in drinking water is around 500 mg/l. (0.5 o/oo).
3. Sodium sulfate and magnesium sulfate have well known laxative effects. However, the dominant anion in sea water is chloride, which apparently has no such effect.
4. 440-500 mg/l chlorides affect the taste of coffee. Sodium has a distinct deleterious effect on the quality of coffee.
5. At concentrations about 5,000 mg/l dissolved minerals, water becomes completely unusable for drinking.
6. The great difference between a detectable concentration and an objectional concentration of neutral salts should be emphasized. People become acclimatized to salts in their water.

Using the sea water phase information developed by Assur (6), the total salinity must be limited to 452 mg/l (0.45 o/oo) to maintain chlorides at the level of 250 mg/l, a reasonable objective for a desalination project. Water of higher quality than this is desirable due to the reservoir problems noted in the introduction.

#### 4.1 Volume of Brine Drainage

Analysis for the quantity and quality of ice grown and shown in Figures 6, 7 and 9, shows substantial runoff of the enriched brines both by surface drainage and by internal gravity movement. It is estimated that 40% of the water applied

Table I  
Chemical Composition of Water and Ice Specimens  
(Percent)

	Standard Sea Water	Kotzebue Water	Strong Brine	Ratio Brine/Water	Low-Salinity Ice	Ratio Ice/Water
Total Solids, ppm	34325	9005	53356	5.92	65.6	0.007
Cl <sup>-</sup> , % Solids	55.5	54.4	55.3	1.02	39.6	0.73
Na <sup>+</sup> , % Solids	30.8	29.0	29.2	1.01	22.8	0.79
SO <sub>4</sub> <sup>=</sup> , % Solids	7.7	6.4	7.7	1.20	11.0	1.72
Mg <sup>++</sup> , % Solids	3.7	3.9	3.9	1.00	2.6	0.67
Ca <sup>++</sup> , % Solids	1.2	1.6	1.8	1.12	3.7	2.31
K <sup>+</sup> , % Solids	1.1	1.3	1.4	1.08	3.2	2.46
HCO <sub>3</sub> , % Solids	0.0	3.2	0.5	0.16	15.7	4.90
SiO <sub>2</sub> , % Solids	0.0	0.02	0.2	10.	1.7	85.0
So <sub>4</sub> /Cl, % Solids	0.139	0.117	0.139	1.19	0.277	2.37



Table II

## Kotzebue Weather, Wind Effects

Month	Temperature			Degree Days		Wind Velocity		Windchill		Days Blowing Snow
	Max	Min	Avg	65°F	32°F	Avg	Fastest	33°C	-0°C	
1965										
October	34	- 3	16.6	1495	472	14.7	43	1250	258	5
November	37	- 5	16.5	1449	461	18.7	51	1300	269	13
December	31	-38	-5.6	2191	1168	13.2	51	1550	600	9
1966										
January	23	-31	-3.6	2129	1106	16.6	46	1600	600	5
February	25	-30	-4.3	1941	1017	13.3	41	1530	580	10
March	20	-42	-12.0	2391	1368	8.9	43	1510	542	3
April	42	-20	9.1	1675	689	12.9	36	1290	360	3

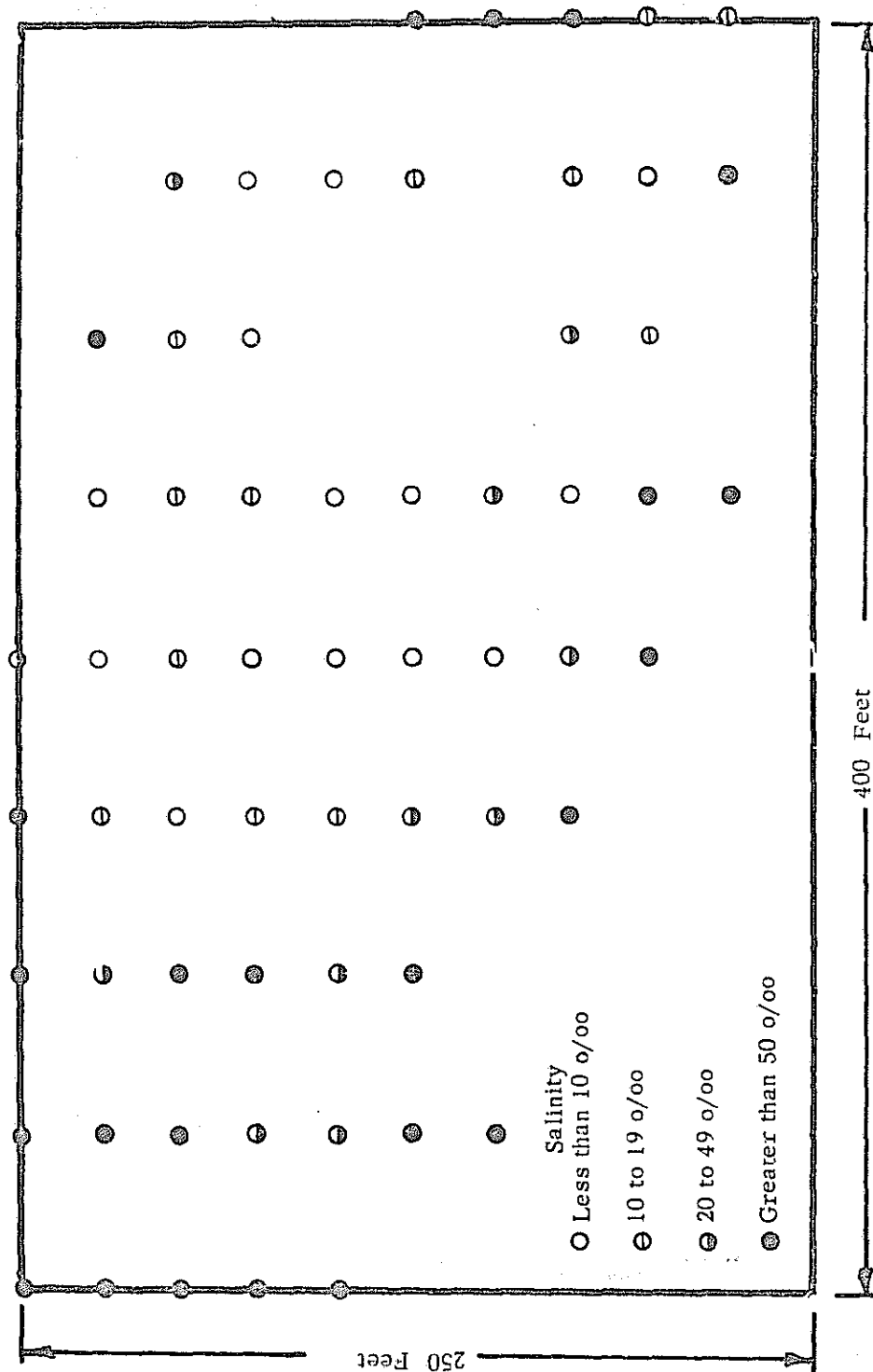
drained away from the point of application by one of these two mechanisms. In all cases, the remaining ice was of much lower salinity than the water from which it was formed, and the water draining away had much higher salinities than the original water. This segregation occurred during the growth process itself, and is not significantly due to gravity drainage. One specific example of the effect occurred on April 3, 1966 with an air temperature of 20°F and little wind. The ice forming near the sprinkler had a salinity of 1.25 o/oo and water moving down the slope had a salinity of 34 o/oo showing the substantial segregation in the applied 7 o/oo sea water. The 1.25 o/oo ice was further reduced to about 0.5 o/oo by gravity drainage three days later.

Some salinity data at the completion of pumping are shown in Figure 15. These data were obtained from water which had collected in the auger holes from which thickness determinations were made on the 28th and 29th of April and show variations from 3 to 65 o/oo. The brines trapped in the auger holes are generally much higher than the adjacent ice because the enriched brines within the ice matrix flowed into the holes. This may be somewhat modified by the possibility of dilution of pure ice melt water draining into the holes as a result of warm weather. The general trend of high concentration of brines at the toe of the slope is self-evident.

Ice cores were removed for more detailed analysis on May 1, with resampling on May 18. These data are shown in Figure 16, and it can be seen that considerable gravity drainage had occurred after pumping was discontinued. This mechanism was evident on the south facing slope, to the left of the figure, which had been both warmed and irradiated by the sun although there was no significant melting. The north slope was not yet warmed as much, and the salinity change was less. Figure 16 shows the brine drainage, because of both growth and gravity drainage, to be downward and outward from the mound. Also shown in Figure 16 is the location of one reference core on the original ice sheet having a salinity of 1.03 o/oo. It can be seen that the brine drainage process was occurring very rapidly with only a few days of warm weather. A major part of the ice mound had been reduced in salinity to potable or near potable standards, with the recovery at that point estimated at 40 percent of the total water pumped.

#### 4.2 Chemical Composition of Ice and Brines

Aliquots of the ice and strong brine samples collected on May 1, 1966 were submitted to the Water Resources Division, U.S. Geological Survey, Anchorage, Alaska for chemical analysis. The results of these tests are shown in Table III, for which standard sea water values from the literature are used as the basis for comparison. The samples are segregated into three types: (1) raw sea water from the vicinity of the test site, (2) strong brines collected May 1, 1966, and (3) low salinity ice collected May 1 from the mounds. Ratios of constituent ions are shown for both the strong brines and low salinity ice as



Brine Salinity Distribution

Figure 15

compared with Kotzebue sea water. It can be seen that the proportional constitution of ions are quite radically changed. The general trend of these results would be expected from the sea ice phase information. Those salts which precipitate at the warmer temperature are held in the ice while those salts which precipitate at colder temperatures are flushed out in strong brine at the toe of the slope. Of particular interest is the very large reduction in total solids which was evidenced in the field by the strong brine areas, being clearly outlined by a yellow color in most cases. It will be noted that the samples used do not reflect a balance of mass transfer. This, of course, would require a very extensive sampling and testing program. The results indicate the following:

1. Sodium and magnesium chlorides remain ionized in the liquid brine and drain the most readily.
2. Sodium sulfate drains less readily, probably due to its much higher precipitation temperature. Brine entrapped in a low salinity ice shows a strong increase in sodium/chloride ratio and also in sulfate enrichment. This is unique to forced sea ice growth and is not found in naturally grown ice sheets.
3. Calcium, potassium, and bicarbonate are quite strongly enriched in the ice.
4. Silica, though low in quantity, is strongly enriched in the ice.

The net result is one of great improvement in water potability because of the high proportional loss in sodium and chloride ions in addition to a general reduction in solids.

### COST OF PRODUCTION

At the present stage of development the equipment used for saline conversion by the forced ice growth process is inadequate for closely estimating the cost of potable water; however, the following table is an outline of costs estimated at this time, based on thirty million gallons per year production at Kotzebue which is the need outlined by the U.S. Public Health Service, Division of Indian Health, Anchorage, Alaska.

#### 5.1 Costs of Water Supply

Using diesel engine driven pumps with the waste heat utilized for prevention of freezing of sea water in pipelines, the estimate is as follows:

Table III  
Brine Analysis

Date	Temperature	Wind Knots	Windchill	
			33°C	0°C
March 13	-28	21	2160	1080
March 12	-23	18	2040	980
March 12	-14	25	1960	950
March 14	-37	5	1700	915
February 28	-24	7	1590	770
April 18	- 5	25	1800	690
April 21	0	15	1550	540
April 11	6	35 (gusts)	1640	500
April 10	10	25	1520	410
April 8	32	25	1110	0
April 27	34	25	1060	0

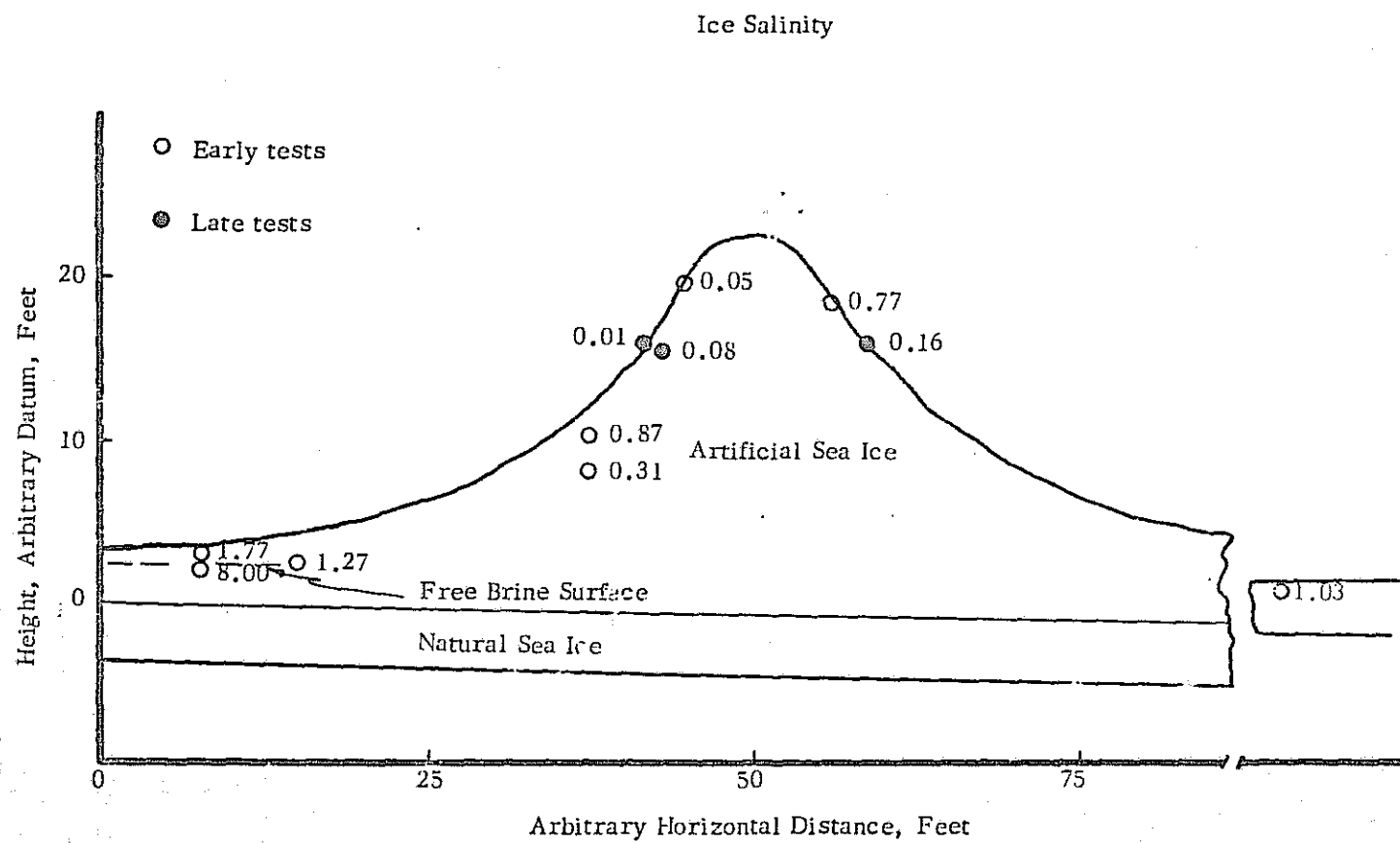


Figure 16

	Cost per 1000 gallons usable water
Fuel: 0.05 gallons fuel at \$0.30/gallon per 1000 gallons water pumped at 40% recov- erable potable water	\$0.0285
Pump and Engine Amortization: 5 year life, 8% interest, and \$6,000 capital cost; \$1,500/year	0.0500
Pipelines, distribution equipment, and site pre- paration: 10 year life, 8% interest, and \$40,000 capital cost; \$5,950/year	<u>0.1983</u>
Saline Conversion Fixed Cost: 40% recovery	\$0.2768
Estimate at 60% recovery is \$0.23/1000 gallons	
Labor, 4 man-years/year at \$7,500/annum	<u>\$1.00</u>
	\$1.28
<u>Reservoir Cost</u>	
20 year life at 8% and \$300,000 capital cost, \$30,600/year	<u>\$1.02</u>
Total cost including reservoir	\$2.30

This compares with present costs during the winter at Kotzebue of 8.4¢ per gallon for fresh ice plus 0.035¢/gallon for thawing energy by diesel fuel, the total cost being about \$87.50 per 1,000 gallons, of which \$3.50 is a fixed energy cost.

Even with the small size of the operation and lack of efficient equipment, the total water cost could be reduced 38 times. It can be seen that the desalination cost is relatively low for such a small system, even including large labor costs and an inefficient reservoir size. The labor estimate could be substantially reduced with development of efficient equipment, but extensive development would probably require the costs to be distributed over more than a single community project.

## 5.2 Cost of Ice Structures, per 1000 gallons, 100% Usable Ice Volume

Fuel	\$0.0142
Equipment Amortization: 3 year life at 8% and \$50,000 capital cost; \$19,400/year	0.647
Labor: 4 man-years/year at \$10,000/year	<u>0.333</u>
	\$1.024

or about \$0.21 per cubic yard, exclusive of manpower logistics costs.

For the desalination, labor is a substantial portion of the total cost, but equipment costs are larger for construction projects due to a shorter amortization period. For large structures, the type of equipment would need to be very large and efficient to reduce the cost significantly. In both applications the energy cost is considerably less than either equipment or labor which were purposefully set high for estimating purposes.

### LOGISTICS

As with most remote field experiments, the logistic effort consumed large quantities of time, effort and money. One is frequently tempted to report this portion of the work in considerable detail, but such will not be done in this case. The camp site in Figure 17 shows the three buildings, designed for air transport, and which were each erected in less than one hour at the site. The problems of electrical power, field transportation, food, housing, equipment and supplies, were adequately solved, and the project ran smoothly in these respects. Making the experimental work fruitful was fraught with the usual difficulties of exploratory field work.

Air transport of the project equipment and supplies was furnished by the Alaska Air National Guard and one C-123 aircraft. The support of the officers and men of the group was extraordinary, and the successes of the project are due in large measure to them. A portion of the loading operation is shown in Figure 18.

### CONCLUSIONS

The objective of this project was to force the growth rate of sea ice in order to study the resulting ice volume from the aspects of desalination of sea water and feasibility of constructing coastal structures.

#### 7.1 Desalination

Desalination was accomplished to standards within the recommendations of potable water set forth by the U.S. Public Health Service.

#### 7.2 Desalination Cost

The estimated cost of desalination by this method shows a reduction in water cost to 1/38 that of present methods for which costs were available. Greater reduction seems attainable with further development.



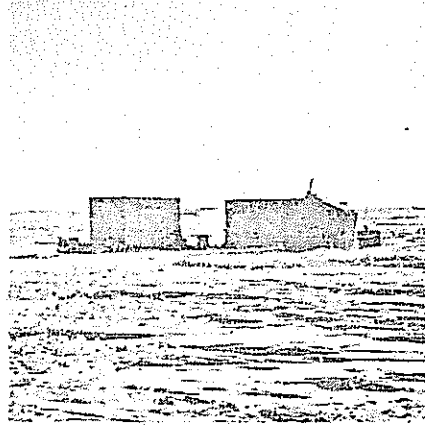


Figure 17      Camp site buildings



Figure 18      A portion of the aircraft  
loading operation

### 7.3 Growth Rate

The growth rate was forced to about 8 inches per day or 125 feet per year minimum. Ice structures to this thickness seem feasible.

### 7.4 Practical Application

This exploratory study has not established detailed techniques for efficient production of either desalinated water or long lived sea ice structures. It has proved, however, the technical feasibility of both, and has shown large economic improvement over existing techniques. Further work is required on the processes themselves prior to prototype projects.

## RECOMMENDATIONS FOR FURTHER WORK

8.1 The geometry of ice volumes for desalination should be optimized from three aspects. First is the land area requirement which is prohibitively large when conical shapes are used with a height of 50 feet or so. The second is the limiting size which would melt the succeeding summer. Third is the mode of brine drainage in large and nonconical shapes. Very little brine segregation would occur during initial freezing by flowing down the sides as occurred during this project. The gravity drainage through a large ice mass needs to be evaluated, both quantitatively and qualitatively.

8.2 The limit of desalination by gravity drainage needs thorough evaluation. If the structure of brine channels is sufficiently open, flushing with fresh water may be economically feasible with considerable improvement in the net salinity.

8.3 Considerably more attention should be given to devices for application of water, particularly the problems encountered with strong winds.

8.4 Strength should be determined for the various types and qualities of ice formed under forced growth. These values change considerably after the first summer due to great changes in brine volume.

8.5 One of the crucial aspects of sea ice structures is the reduction of summer ablation and deterioration. It is known that the mechanism of greatest magnitude is the absorption of ultra-violet radiation which disintegrates and internally melts the ice to a depth of several feet. Economical methods of prohibiting ultra-violet transmission into the ice include pumping bottom sediments with the water, thus rendering the ice opaque. This and other methods need study.

8.6 Concurrent with additional field experiments should be laboratory controlled experiments designed for detailed observations of selected factors including gravity brine drainage; brine constitution changes; water droplet heat transfer; ice formation by droplet application; ice disintegration due to

ultra-violet transmission; bulk ice melt rates due individually to conduction, convection and radiation; the study of protective coverings to reduce evaporative cooling during melt; and effective means of ablation control on ice structures.

## REFERENCES

- (1) Malmgren, Fainn. O svoistvakh morskogo l'da. (The properties of sea ice). Sci. Res. Norwegian North Pole Exped. with the Maud, vol. 1, no. 5 (1927).
- (2) Nelson, K., and T. Thompson. Deposition of salts from sea water by frigid concentration. Univ. of Wash., Dept. of Oceanography, Tech. Report 29, Seattle (1954).
- (3) Kingery, W. D. and W. H. Goodnow. Brine migration in salt ice. Ice and snow, properties, processes, and applications. M.I.T. Press (1965).
- (4) Dykins, J. E. and A. I. Funai. Point Barrow trials - FY 1959; investigations on thickened sea ice, U.S. Naval Civil Engineering Laboratory Technical Report 185, Port Hueneme, Calif. (January, 1962).
- (5) U.S. Department of Health, Education, and Welfare, Public Health Service. Public Health Service drinking water standards, Revised 1962, Washington, D.C.
- (6) Assur, A. Arctic sea ice; composition of sea ice and its tensile strength. Nat. Acad. Sci. Natl. Research Council Publ. 598, 106-138 (1958).

1	Accession Number	2	Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM	
W	70-02113		02C, 02K		
5	Organization	Alaska Univ, College, Arctic Environmental Engineering Lab.; and Alaska Univ., College. Inst. of Water Resources.			
6	Title	SALINE CONVERSION AND ICE STRUCTURES FROM ARTIFICIALLY GROWN SEA ICE,			
10	Author(s)	16	Project Designation		
	Peyton, H.R.; Johnson, P.R.; Behlke, C.E.		OWRR Proj No B-001-ALASNA		
		21	Note	-Res-partially supported by OWRR, Dept- of Interior-	
				PB190 371	
22	Citation	Univ Alaska Arctic Environ Eng Lab Res Rcp No 4, Sept 1967. 30 p, 18 fig, 3 tab, 6 ref.			
23	Descriptors (Starred First)	*Desalination, *Construction materials, *Ice, *Freezing, *Sea water, Cold regions, Costs, Sea ice, Cryogenics, Crystal growth, Crystallization, Desalination processes, Construction.			
25	Identifiers (Starred First)	Ice construction engineering.			
27	Abstract	In cold regions, desalination by freezing sea water was studied as a possible economical process. Power requirements are greatly lowered by using low winter temperatures to freeze water and using the summer's adequate solar energy to remelt it. The use of frozen sea water as a structural material was also studied. At high enough latitudes, summer ablation can be controlled to the point that major structures made of ice will last through the summer. Material costs should be low. (Knapp-USGS)			
Abstractor		Institution			
George Knapp		U.S. Geological Survey, Water Resources Division			
12/29/69					
WR-102 (REV JULY 1969) WRSIC		SEND TO: WATER RESOURCES SCIENTIFIC INFORMATION CENTER U.S. DEPARTMENT OF THE INTERIOR WASHINGTON, D. C. 20240			

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